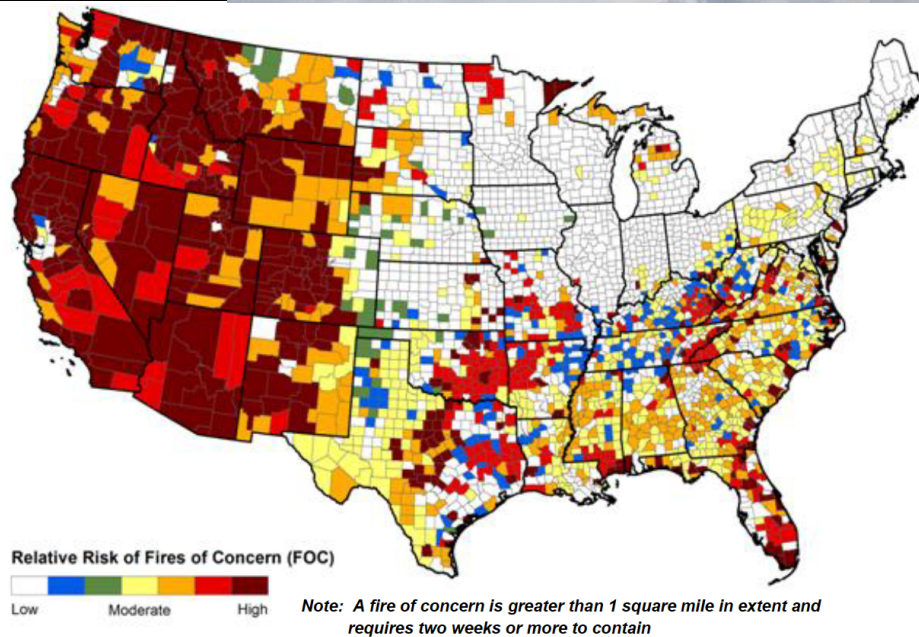


Fire Influence on Regional and Global Environments Experiment (FIREX)

The Impact of Biomass Burning on Climate and Air Quality: An Intensive Study of Western North America Fires



NOAA Field and Laboratory Studies during 2015-2019

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The Impact of Biomass Burning on Climate and Air Quality: An Intensive Study of Western North America Fires

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Motivation and Objectives

A combination of a warmer, drier climate with fire-control practices over the last century have produced a situation in which we can expect more frequent fires and fires of larger magnitude in the Western U.S. and Canada. Present-day forest ecosystems have evolved with wildfire as part of their natural environment. Forests benefit from periodic fire to promote seed germination and healthy ecosystem succession. The 20th century saw fire suppression become the standard response to wildfires, especially in western North America. This fire suppression has led to a buildup of fuels in forested areas, a breakdown in the natural ecology of forests, and an underestimate of the risks associated with the development of the urban-wildland interface. Prescribing fires, and allowing some naturally-occurring fires to burn are some of the management practices that can address the above problem [*U.S. Dept. of Interior*, 2014]. In addition to the direct risks of fire, other risks include atmospheric impacts on air quality, climate, and health.

Climate change will sharpen the problems involving wildfires in the western U.S. The average area burned per year by wildfire in parts of the western U.S. is projected to increase by “two to four times per degree of warming” [Warming world: Impacts by degree, National Research Council, 2011]. Wildfire activity increases in the Western US in the past several decades have been linked to higher temperatures, earlier snowmelt, changing precipitation patterns, and drought impacts on moisture levels in vegetation and soils, which appear at least as important as fire management practices to determining fire frequency in the West [*Westerling et al.*, 2006; *Dennison et al.*, 2014; *Sherriff et al.*, 2014]. There are urgent needs to better understand the impacts of wildfire and biomass burning (BB) on the atmosphere and climate system, and for policy-relevant science to aid in the process of managing fires.

NOAA’s Office of Oceanic and Atmospheric Research (OAR) has as part of its core mission “(to) advance understanding and prediction of the Earth System to enhance society’s ability to make effective decisions” [*NOAA/OAR*, 2014]. The research program proposed here outlines a comprehensive research effort to understand and predict the impact of North American fires on the atmosphere and ultimately support better land management.

State of Science and Scientific Background

Fire impacts occur over various time and distance scales from local to global via many complex, interdependent, and poorly understood, processes. For example, fire dynamics and meteorology determine the vertical profile of smoke injection which then governs the photochemical environment and transport of the fire plumes: e.g. how they are processed and therefore their chemistry and how far fire emissions are transported regionally and globally. Major critical research areas are summarized briefly below including priority areas that require more research.

Numerous recent studies, listed in Table 1, have contributed to the characterization of the complex nature of fire emissions and processing. Studies led by NOAA include ICARTT, which found strong BB influence from Canadian and Alaskan fires in the northeast U.S.; ARCPAC, which found a strong contribution by Asian fires to arctic haze over Alaska; and SENEX, which acquired data on the relative contribution of BB to organic aerosols and gases in the southeast U.S. and the first-ever nighttime smoke sampling. Recent airborne studies led by other agencies include the NASA ARCTAS and DC3/SEAC4RS missions, and the DOE BBOP mission. ARCTAS produced new information on emissions and processing of boreal fires. DC3, SEAC4RS, BBOP produced new information on emissions and smoke evolution regarding western U.S. wildfires, cloud processing of smoke, and agricultural burning in southeast U.S. Recent laboratory studies like the University of Montana led FLAME-4 study produced some fuel specific emission factors (EFs) and smoke aging simulations.

Although scientific analysis of the more recent missions is still ongoing, future missions aimed primarily at BB are still needed to address inadequacies in the experimental datasets, with foci including observation of night-time plume evolution and air quality impacts, better gas- and aerosol-phase tracking of chemical processes, and brown/black carbon chemistry and absorption attribution. An aircraft such as the NOAA WP-3, equipped with state-of-the-art instrumentation, would provide the most complete airborne platform ever to be dedicated to BB research.

Table 1: Recent field studies relevant to biomass burning research

Acronym	Campaign Name	Year	Location	Sponsor
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation	2004	Northeast US	NOAA
ARCPAC	Aerosol, Radiation, and Cloud Processes affecting Arctic Climate	2008	Alaska	NOAA
SENEX	Southeast Nexus	2013	Southeast US	NOAA
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites	2008	Canada	NASA
DC3	Deep Convection Clouds & Chemistry Experiment	2012	Southeast US	NASA
SEAC4RS	Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys	2013	Western US	NASA
BBOP	Biomass Burn Observation Project		Washington, Tennessee	DOE
FLAME-4	Fire Lab at Missoula Experiment-4* * laboratory study	2012	Montana	NOAA, NASA, NSF, DOE

Fuel-specific Emission Factors

Fuel-type-specific emission factors are a fundamental need for prediction and assessment of wildfire impacts on the atmosphere. In practice, there are a number of factors that complicate emission estimates. The materials emitted, and their emission intensity, depend on combustion processes: e.g. flaming and smoldering, but real fires are always a combination of these regimes. For this reason, emission ratios are usually measured and reported as a ratio to one of the two main carbon species emitted, carbon monoxide (CO, from smoldering) and carbon dioxide (CO₂, from flaming). Emission factors are frequently modeled as a function of a parameter called modified combustion efficiency (MCE), defined as:

$$\text{MCE} = \Delta\text{CO}_2 / (\Delta\text{CO}_2 + \Delta\text{CO}) \quad (1)$$

MCE accounts for much of the variability in emission factors and is dependent only on ΔCO and ΔCO_2 , which are easily measured in the atmosphere and in laboratory fires. Emissions of some nitrogen-containing species also follow this pattern (e.g. NO_x from flaming). It should be noted that in contrast to other combustion sources, e.g. fossil-fuel power plants or vehicles, the nitrogen emitted from normal convective biomass fires (i.e. wildfires) comes entirely from the fuel and not from atmospheric nitrogen.

The literature on wildfire emission factors is extensive, as exemplified by several recent reviews [Akagi *et al.*, 2011; Yokelson *et al.*, 2013]. There has been significant progress in defining and quantifying the detailed chemistry of BB emissions as analysis methods applied to these measurements continue to evolve in sophistication. Examples of recent new findings include measurements of isocyanic acid (HNCO) emissions and the observation of nitrous acid (HONO) as a consistent product of fires in both the laboratory and field at levels of 5-30% of NO_x [Burling *et al.*, 2010; Roberts *et al.*, 2010]. There has also been increased effort to obtain detailed information on the semi-volatile organic compounds (SVOCs) that are an abundant class of secondary organic aerosol (SOA) precursors in fires. Attempts to reconcile the VOC emissions from fires with the observed SOA formation have shown that unidentified SVOCs, while perhaps only 20-50% of the VOC emitted [Hatch *et al.*, 2014; Stockwell *et al.*, 2014], can have a disproportionately large effect on the amount of SOA estimated by models [Jathar *et al.*, 2014; McMeeking *et al.*, 2014]. Recent laboratory work has led to the recognition that the relative amounts of BC and organic carbon aerosol (OC) emitted are strongly relevant to the optical properties because of light-absorbing OC aerosol (also called “Brown Carbon”, BrC) [Saleh *et al.*, 2014].

Even with the application of new analytical techniques to fire emissions measurements, a significant fraction of VOCs and SVOCs remain unidentified. A better process-level understanding is needed on gas and particle emissions from North American wildfires. More emission factors for the gas and particle phase are needed for various fuels and conditions (e.g. moisture and wind) from typical North American wildfires. A systematic effort is needed for a comprehensive budget of carbon- and nitrogen-containing materials. This information can then be integrated with land-use and ecosystem data to provide the data products needed for assessment and modeling of wildfire impacts.

Smoke

Smoke is one of the most prominent and visible aspects of BB. Smoke is primarily comprised of gaseous and aerosol constituents including BC, BrC, OC, and mineral dust, all of which have critical climate and health impacts. The aerosol, controlling most of the optical properties, evolves due to dilution, coagulation, and chemical processing on time scales of seconds to days [Vakkari *et al.*, 2014]. BB smoke has many impacts on the atmosphere; depending on the relative amounts of OC and BC/BrC and surface albedo, it can either heat or

cool the atmosphere; it can provide ice and water active aerosols; affect visibility and air quality; be transported over global scales. BB is the largest source of black carbon to the atmosphere [Bond *et al.*, 2013] and a singularly important source of BrC. There is evidence that fires produce BC particles coated with particulate organic matter in a manner that enhances some of their optical properties, specifically short wavelength absorption by “lensing” [Lack *et al.*, 2012]. However, the net effect of all aerosol species generated by BB is currently believed to be slightly cooling.

Satellite Emissions Estimates

The aggregation and systematic accounting of fire emissions on regional to global scales relies on satellite-based detection of visible and infrared irradiance, and some broadly applicable fire indicators such as carbon monoxide or aerosol optical depth. Models have been constructed to use these detected parameters, along with land-use, and emission factor data to produce inventories for fire emissions. These inventories are essential to the inclusion of fire emissions in global chemistry and climate models. It is widely accepted that current satellites undercount wildfire and domestic BB due to limited spatial resolution, clouds, and orbital gaps. In addition, there are limitations in the application of retrieval algorithms to fire situations.

Higher resolution fire products will be developed by other agencies using the next generation of satellites, including not just fire detection, but also chemical species such as carbon monoxide and aerosol optical properties. These enhanced products need to be integrated with the best available fire dynamics and emissions data from laboratory and field measurements. Within NOAA, data from intensive field projects involving wildfires, along with regional chemical-transport modeling, will be used to test these satellite products and provide ground-truth for their continued improvement.

Transport, Transformation and Plume Chemistry

The impact of wildfires on regional- to global-scale atmospheric chemistry depends on the physical and chemical transformations that take place as fire emissions are transported, diluted, and exposed to chemical oxidants. Ozone and other oxidants can be formed along the way, and particle mass-loadings can grow or shrink [Akagi *et al.*, 2012]. In addition, toxic gas and particle materials that have health impacts can be both formed and destroyed. Not all the factors that govern these processes are well understood, and individual fire plumes can have very different behaviors. Fire emissions contain a number of unusual compounds, some of which may have specific health effects [Roberts *et al.*, 2011], and more compounds are being discovered as more sophisticated analytical techniques have been applied [Stockwell *et al.*, 2014]. Fundamental atmospheric chemical behavior of some of these compounds is often unknown.

Photooxidation of the NO_x and VOCs emitted by fire plumes shows complex behavior, sometimes leading to production of ozone and sometimes not [Jaffe and Wigder, 2012]. The reasons for this complexity are not understood and may have to do with how fast the plume was lofted and cooled, how efficiently NO_x was converted to products such as peroxyacetyl nitrate (PAN), or whether the fire had substantial amounts of radical precursors such as HONO or carbonyls. What is clear is that fire emissions often have broad-scale impacts on ozone formation [Pfister *et al.*, 2006; Wotawa and Trainer, 2000], especially when mixed with urban emissions [Singh *et al.*, 2012], and can be decisive factors in triggering air quality exceedances. Policy mechanisms exist for jurisdictions to apply for waivers due to wildfire impacts. A much better understanding of the photooxidation in fire plumes is needed to predict impacts of wildfires and prescribed or permitted fires. In addition, nighttime processing of fire plumes is likely to be very

important considering what we know of NO_3 and N_2O_5 chemistry in NO_x -containing plumes, but has received almost no attention thus far.

The physical and chemical processes governing the transformation of particles in BB plumes is quite complex, with evidence of both loss and gain of particle mass, and rapid atmospheric oxidation [Vakkari *et al.*, 2014]. Mass can be lost as smoke is diluted due to the physical equilibration of semi-volatile compounds [Robinson *et al.*, 2007]. Oxidation of both gas and particle phase compounds due to reaction with HO_x radicals (daytime) and NO_3 radicals, N_2O_5 , and ClNO_2 (nighttime) can lead to mass loss or gain, and changes in the optical properties. The chemistry and surface coating properties of particles emitted by fires evolve as these physical and chemical changes take place and affect the optical, cloud nucleation, and toxicological properties of the particles. A proper description is essential for analyzing and predicting the impacts of BB.

Regional Atmospheric Chemistry and Impacts

Wildfires can have profound impacts on regional air quality due to promotion of photochemical ozone production, particle pollution of both primary and secondary origin, and emission of toxic materials. These aspects of wildfires have the most immediate effect on populations and ecosystems, and are a high priority when making decisions on fire management, i.e., when to plan prescribed burns and when to allow fires that started naturally to burn. The research needed to understand and manage these impacts is one of the more challenging aspects of wildfire research, as it involves understanding all of the smaller-scale processes detailed above: fire weather, emissions, and transport and transformation. This information must then be incorporated into models that can be used to make policy decisions on all timescales, from the immediate: e.g. fire management and health advisories, mid-term: air quality waiver, to the long-term: ecosystem and urban-wildland interface management. As National Ambient Air Quality Standards (NAAQS) for ozone and other criteria pollutants are reduced in the future, meeting these stricter standards will require better understanding and prediction of fire impacts (along with long-range transport of pollution from other parts of the world).

Fire Dynamics and Fire Weather

The physical development and dynamics of wildfires on local to regional scales govern how fires impact their immediate environment, including the safety of first responders on the scene, and the air quality of local communities. The development and collapse of strong vertical transport caused by fires can control the rate of vertical transport of heat and chemical emissions, and even create intense pyrocumulus systems. The starting conditions and processes that govern vertical transport are still quite uncertain, making prediction difficult. The duration and extent of these convective systems are crucial features that determine the initial transport of emissions and need to be better understood. Finally, pyroconvection can also cause super-cooled air masses leading to intense downdrafts, with winds that radiate unpredictably upon impacting the ground, thereby accelerating fire propagation.

Global Distributions and Impacts

The impacts of wildfires are mostly associated with short-term climate forcers; ozone and aerosols including BC, BrC and OC. Global climate impacts of BB result from its truly massive contributions to aerosol optical depth (AOD) over large areas. Regions such as the Arctic and the cloud decks of South America are uniquely sensitive to BB emissions and to secondary processes, such as cloud and ice nucleation that can magnify the radiative impact of the emissions. The research needed to advance our understanding of these impacts is broad on both spatial and

temporal scales, and relates to a wide spectrum including BB inventories, satellite fire detection, chemical evolution of gaseous species, aerosol microphysical and optical properties, proper integration into models, interactions with warm, mixed phase, and ice clouds, and effects on the vertical structure of the thermal profile. For example, current fire emissions inventories undercount small fires and domestic BB because they are based on satellite fire detection schemes that have limited resolution and therefore regional airborne measurements of fire products are invaluable in assessing inventories. Improving the integration of wildfires and BB into global models requires more detailed emission estimates at finer spatial scales and better understanding of how to represent these emissions in relatively coarse-resolution treatment after significant chemical processing and dilution. These efforts will require combining new chemical details from emission measurements, new insights about chemical and physical transformation of smoke, supported by observations from the next generation of satellites.

The new science and capabilities FIREX will generate

The FIREX research effort will target critical unknowns about BB that can be realistically addressed in the next five years with existing or new technologies, laboratory and field studies and interpretive efforts. The following describes several aspects that will add new science and capabilities to the results from previous laboratory and field studies that were described above.

1) New instrumentation has become available, or will be developed, that has not been extensively used in previous field campaigns. For FIREX we will use these new technologies throughout campaign.

- Measurements of previously unidentified compounds using new mass spectrometry techniques ($\text{H}_3\text{O}^+\text{CIMS}$, I^-CIMS , nitrate-CIMS, 2D-GC-MS, TAG-MS ...)
- Broadband extinction measurements of BrC augmented with polar scattering measurements
- Studies of lensing of black carbon using a thermally desorbed photoacoustic instrument
- Electropray mass spectrometry for aerosol-phase compounds

2) In the first years of FIREX we will conduct laboratory and small-scale studies to answer specific questions and that will be integrated into the planning and execution of the large-scale field campaign.

- Fire Science Laboratory experiments to characterize emissions before and after the large-scale field campaign
- Atmospheric simulation chamber experiments on chemical transformation
- Investigations of aged fire emissions from a ground site (Storm Peak, Colorado)
- Testing and validation of new instrumentation

3) We have the ability to simultaneously deploy multiple platforms in the field to evaluate the atmospheric impact of BB more thoroughly than ever before. Airborne sampling at various scales can be performed simultaneously with ground-based sampling both during the day and at night. In past campaigns, such as SENEX, we have collaborated with multiple groups and agencies that have added significantly to our proposed research and supplemented the payloads or provided different platforms as needed.

- NOAA WP-3 aircraft to do a major emissions and chemical transformation study for multiple fires in coordination with other platforms
- Mobile laboratory to investigate smoldering emissions that are not lofted and stay at ground level particularly during nighttime. These emissions are likely different in composition, and undergo processing that is different than plumes aloft, but are often the ones that affect local air quality the most.
- Twin Otter, other small aircraft or unmanned aerial systems (UAS) to do near field emission study to understand the temporal evolution of emissions

4) Nighttime fires and smoke processing have been under-sampled, and indeed largely ignored, despite evidence for prodigious nighttime smoke production (e.g. on the 2013 Rim Fire or Vermote et al., 2009). NOAA has extensive experience in measurement and interpretation of nighttime chemical processing that will be applied here. Our mobile laboratory is suited to measuring the ground-hugging smoke at night.

5) We will relate the microphysics of particulate matter (size distribution, black carbon mass, etc.) to satellite and climate-relevant properties such as the light scattered at particular angles measured by satellite and the scattering and absorption of light at ambient humidity.

6) The results of the laboratory, small-scale studies, and satellite observations will be incorporated with the data from the large-scale intensive study and modeling efforts.

FIREX Science Questions

The following is a list of specific science questions that can be addressed using a combination of the large-scale NOAA WP-3 field campaign and the smaller-scale field and laboratory experiments.

1) What are the emissions of gases, aerosols, aerosol precursors and greenhouse gases from North American fires?

- How well do inventories represent BB emissions?
- How do the relative amounts of smoldering and flaming impact smoke chemistry and injection altitude?
- What is the composition and volatility of the previously unidentified fraction of the emissions?
- What are the emissions of previously unidentified SVOCs, IVOCs, and BC, BrC and OC aerosols?
- What are the emissions of greenhouse gases methane and N₂O?
- What are the emissions of air toxics?
- Does meteorology, such as humidity and temperature, influence the emissions of trace gases and aerosols?

Approach: After development in the laboratory, new instruments will be used in the fire science laboratory to identify previously unidentified compounds and understand their importance. Emission factors determined in the lab will be compared to near-field measurements during the preparatory and intensive field studies using the mobile laboratory for smoldering and the NOAA WP-3 and Twin Otter aircraft for flaming plus smoldering emissions.

2) What is the chemical transformation of those emissions?

- What are the formation mechanisms for secondary species (ozone, SOA and sulfate) and what environmental or chemical conditions control their relative importance?
- How does the chemical transformation change with meteorological conditions?
- How do nighttime chemical transformations involving NO_3 , N_2O_5 and O_3 influence the composition and evolution of smoke plumes?
- How important is nighttime chemistry for production of secondary organic aerosol and brown carbon aerosol in smoke?
- What are the mechanisms that lead to PAN formation in fire plumes during daytime and nighttime?
- What is the diurnal cycle of free radical and oxidant production in fire plumes, and how important are reactions with different oxidants at various times of day?
- How important is the formation of organic aerosol from aqueous-phase processes?

Approach: Fire emissions will be aged in the CIRES atmospheric simulation chamber with specific focus on the identified SVOCs and VOCs. The NOAA WP-3 aircraft will be used to track the chemical evolution in the field.

3) What is the local air quality and visibility impact of North American fires?

- How does local meteorology impact fire evolution?
- How well do local models predict the BB impact on air quality and visibility?
- How important is nighttime smoke for populated areas and what are the health impacts?

Approach: The NOAA WP-3 aircraft will be used to map out the extent of the fire plume and the mobile laboratory will be used in populated areas to measure concentrations of fire emissions. The results will be compared to local and regional models, and ground and mobile-lab observations will be used to assess population exposures to fires.

4) What are the regional and long-term impacts of North American fires?

- How strongly are the composition and distribution of pollutants over North America influenced by BB?
- How far afield can BB emissions from common, but smaller fires impact air quality?
- What are the future changes in BB impacts as a result of climate change and changes to fire management practices?

Approach: The Storm Peak station is often influenced by long-range transport of BB emission. We will determine the air pollutant contribution from fire emissions during the burning season. With the NOAA WP-3 we will probe aged smoke plumes within the reach of the aircraft throughout North America.

5) What are the climate-relevant properties of BB aerosols?

- What are the extinction, absorption and CCN properties of BB aerosol as a function of smoke age on hours to days time scale?
- What role does brown carbon and coatings on black carbon particles play in the optical properties of smoke?
- How should BB aerosols be assessed via remote (i.e. satellite) observations?
- What fraction of the organic aerosol is primary versus secondary at various time scales?
- How well do regional and global models predict the BB influence on climate?

Approach: Aerosol extinction, absorption and cloud nucleating properties will be measured from the aircraft for different fire types. Correlating the variability in aerosol with inert tracers of BB such as acetonitrile will describe the fraction of aerosol that is primary versus secondary.

Research Strategies and Activities

We summarize an integrated strategy using ongoing and proposed research on BB within NOAA/OAR that coordinates efforts, based in part on the above science questions. Research will take place on scales ranging from the flame-front to the global atmosphere. The FIREX campaign will be a multi-year effort, with methods development, small- and large-scale laboratory and field experiments. The initial research will include new instrument development that will be used throughout all parts of the FIREX campaign. The laboratory and field experiments will include:

- Emission factor measurements from typical North American fuels in the fire science laboratory in Missoula, Montana
- CIRES atmospheric simulation chamber studies of the chemical evolution of fire emissions
- Mobile laboratory deployments
- Ground site measurements at Storm Peak, Colorado often influenced by BB from several western states
- Small aircraft deployment with the NOAA Twin Otter or similar aircraft for assessment of emission factor estimates

The results of these activities will yield immediate answers to some of the science questions and will be incorporated into our understanding to provide the necessary scientific background for a large-scale field experiment in 2018 that will have the NOAA WP-3 aircraft at its center and include many of the other smaller platforms. The strategy and a proposed timetable for the specific activities are outlined below and the expected outcomes discussed. The research strategies described below are based on current understanding, knowledge and capabilities, with some reasonable projections based on institutional experience.

Table 2: Proposed activity timetable

		FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
		Individual Activities			Intensive	
1	Instrument, model development initial lab and field experiments					
2	Emission data incorporation in inventories and model development					
3	Fire lab: emission factors, compound identification (typical NA fuels)					
4	Simulation chamber study for chemical transformation of new compounds					
5	Field observations with small aircraft, mobile lab and ground site					
6	Large multi-platform intensive					
7	Fire lab and simulation chamber: (2018 intensive measured fuels)					
8	Coordinating studies with other agencies, Interpretation and Analysis					

- FY with major work for activity
- FY with minor work for activity
- FY with large-scale field experiment

1. Instrument, Methods, and Model Development

Improved measurement techniques, analysis methods, and model approaches are required to address the research needs outlined above. Considerable development activities will need to be undertaken to adapt and improve physical and chemical measurement techniques to study fires. Regional photochemical transport models incorporating fire emissions and chemistry will need to be refined to provide guidance on the impact of fires on air quality and climate.

- Gas phase – reduced nitrogen compounds, SVOC, IVOCs and VOCs
- Particle phase – Optical Methods, SOA precursors, possibly ice nucleation
- Fine-scale meteorological measurements and model development

2. Initial Laboratory and Field Experiments

Laboratory and small scale field projects will be undertaken to address questions regarding chemical composition and processing associated with BB, develop and test new technology, and demonstrate field readiness. These studies will involve measurements of process-level parameters, optical properties, as well as chemical transformation of fire emissions. Test measurements using the developed methods and chemical mechanisms will be undertaken locally and at sites of opportunity in the western U.S., e.g. at the CIRES atmospheric chemistry simulation chamber, the NOAA Boulder mesa site, or Storm Peak laboratory.

- Measure rates and develop mechanisms for key gas and heterogeneous-phase reactions
- Measure fixed nitrogen balance in BB plumes (new and aged)
- Quantify key semi-volatile organic compounds (SVOCs)

3. Emissions Data Incorporation and Inventory Development

Current knowledge and updated data bases on fire emissions need to be incorporated into products that can be used for air quality and global models by the modeling community. The next generation of satellites presents the opportunity for higher resolution fire detection leading to more accurate fire counts and better observation of fire products leading to improved top-down constraints. Several groups in collaboration with NOAA/CSD will use these data to improve satellite detection, emissions estimates, observations, and satellite retrievals.

4. Fire Lab Study

A coordinated effort based at the USDA Fire Lab in Missoula, Montana is envisioned during FY2016 and 2019. Experiments will focus on refining our understanding of emissions and short timescale processing using the instruments and methods that have been developed during the first years of this project. The focus will be on measuring fuels or combustion conditions that are characteristic of the western US that may be under-sampled by the fire research community and in the follow-up study of fuels from fires observed during the 2018 intensive field study.

- Fixed nitrogen budget and its chemical evolution
- Identification of unknown SVOCs and VOCs
- Multi-phase distribution of SVOCs
- Optical properties of fresh and progressively aged particles

5. CIRES Atmospheric Simulation Chamber Study

A coordinated effort at the CIRES atmospheric simulation chamber is envisioned during FY2017. The chamber is a newly developed facility at CU Boulder, headed by Profs. Ziemann and Jimenez. The study will focus on the atmospheric chemistry of a range of VOCs that are unique to smoke, for example aromatic aldehydes, alcohols and acids. Previous work has shown that these compounds may be among the most efficient precursors for SOA formation in smoke,

but the amount of previous work is very limited making these conclusions highly uncertain. The experiments will serve to better understand the aging of smoke in the atmosphere, as well as to identify specific marker compounds that can be used in the interpretation of field data. The chamber facility has a sample preparation room that allows the injection of real smoke into the chamber. Previous work has shown that the aging of smoke in a chamber can lead to significant SOA formation for some fuels, but none for others. The dependence of these differences on smoke composition are not well understood, hindering the description of smoke impacts on regional atmospheric environments.

6. Field observations with small aircraft, mobile lab and ground site

Small-scale field experiments will be conducted to investigate specific aspects of BB influence on the regional atmosphere.

- UAS measurements of meteorological parameters including RH (fire weather), particle number density (primary aerosol). Other desired measurements include CO and CO₂ for MCE determination
- Small aircraft, e.g. Twin Otters for source determination (CO, CO₂, aerosol, organics)
- Mobile laboratory for near-source ground observations where aircraft cannot easily access, especially at night
- Measurements at a high-elevation site, for example the Desert Research Institute Storm Peak Laboratory (SPL) in Colorado, are sensitive to wildfire emissions across a significant fraction of the western U.S. Long-term measurements by NOAA's Global Monitoring Division at SPL have shown summertime increases in aerosol absorption that are likely due to wildfire emissions. Measurements at this site, in parallel with the intensive NOAA WP-3D mission, can be used to make a more detailed chemical and microphysical characterization of dilute, aged smoke, as well as provide an additional time series to quantify emissions in the western U.S. using inverse modeling.

7. Large-scale coordinated intensive field study

A field intensive involving heavy aircraft, ground/mobile platforms and satellites will be conducted during wildfire season in the summer of 2018. This effort will involve chemical and physical characterization of fire plumes from the local to the regional scale with the goal of obtaining real world data on the impacts of fires on the atmosphere. The effort will be focused on the wildfire season; however, the difficulty in predicting locations of wildfires might require us to choose several possible bases of operation and have the option to transit among them and deploy from any one of them for a period of time. Surface-based experiments will need to be deployable on short notice and moveable during the project.

- NOAA WP-3 aircraft for measurements on medium to regional scales and from boundary layer to the middle of the troposphere.
- Rapidly deployable ground and mobile site(s) to include local scale chemical and physical measurements and UAS.
- Mobile laboratory to provide medium-scale surveys of fire impacts
- The Twin Otter (or other small aircraft) for detailed emission studies in coordination with the WP-3. For example, the Twin Otter could study how the emissions change in the first few hours, while the WP-3D is flying downwind to study the chemical evolution on day to multi-day timescales
- Satellite observations of fire and plume locations and intensities, optical properties, and chemical constituents

8. Interpretation and Analysis

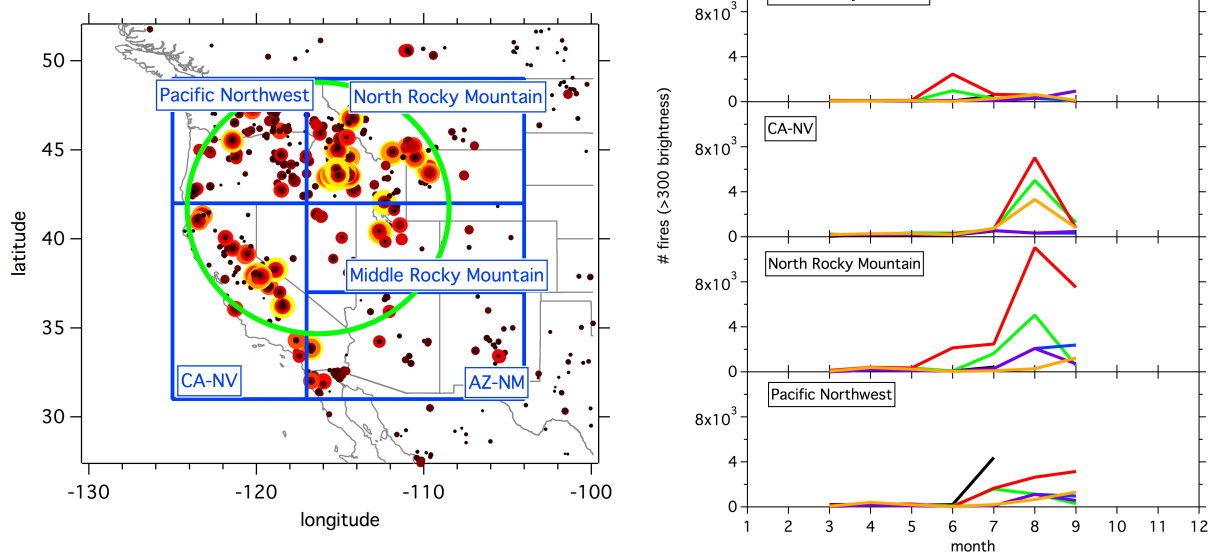
The results of the above activities will be continually assessed and used to update and refine the project goals and plans. The general areas of interest will be those that further our understanding of wildfire and BB impacts on the atmosphere.

- Regional models can be used to assess the larger scale significance of processes discovered or elucidated in the laboratory and field studies. They can be used to develop computationally efficient parameterizations for global models, while the models can in turn be validated by the field observations.
- Nitrogen and carbon balances of fire emissions, and assessment of emissions factors of new compounds, BrC and BC.
- Chemical reaction rates and mechanisms of compounds specific to wild fires and BB.
- Emissions inventory construction and verification
- Meteorological and chemical model validation
- Refinement of satellite chemical and optical property observations

Timing, Location, Logistics

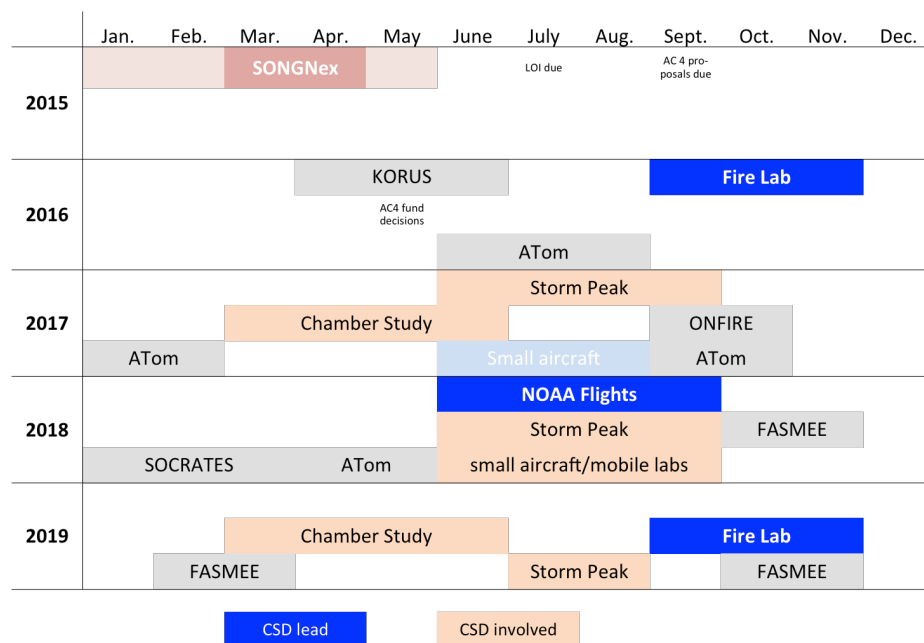
The choice of deployment locations will be informed by the historical fire locations and timing as shown in Figure 1. Around August in the north-western US have always been fires that would have been reachable with the NOAA P3 aircraft in a single flight indicated by the green circle in Figure 1.

Figure 1: Location and intensity of fires in August 2013 and the number of fires during the past six years in five different areas in the Western US.



The tentative timing of the various proposed and possible FIREX activities is shown in Figure 2 together with major fire related activities from other agencies.

Figure 2: Calendar of possible FIREX activities.



Deliverables

This vital policy-relevant science will be crucial to adapting to a future with increased wildfires. The results of these studies will provide the scientific basis for:

- Improved fire weather analysis to aid first responders and fire managers
- Quantitative assessment of population exposures to toxics from fires
- Measures of air quality impairment from ozone and primary or secondary particles
- Improved understanding of fires as sources of brown and black carbon
- Better descriptions of fire dynamics and transport on local to regional scales
- Better estimates of the impacts of fires on climate

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